# Fundamentals & Basics of GMAW

## 1.0 INTRODUCTION:

Gas Metal Arc Welding (GMAW) is an arc welding process (Figure 1) wherein the arc is established between a continuous consumable electrode (wire) and the work piece. An external supply of gas or gas-mixture provides the necessary shielding to the arc and the molten pool. The welding process can be accomplished with significantly higher deposition rates over the shield metal arc welding. The absence of fused slag facilitates this process with minimum post-weld cleaning requirements.

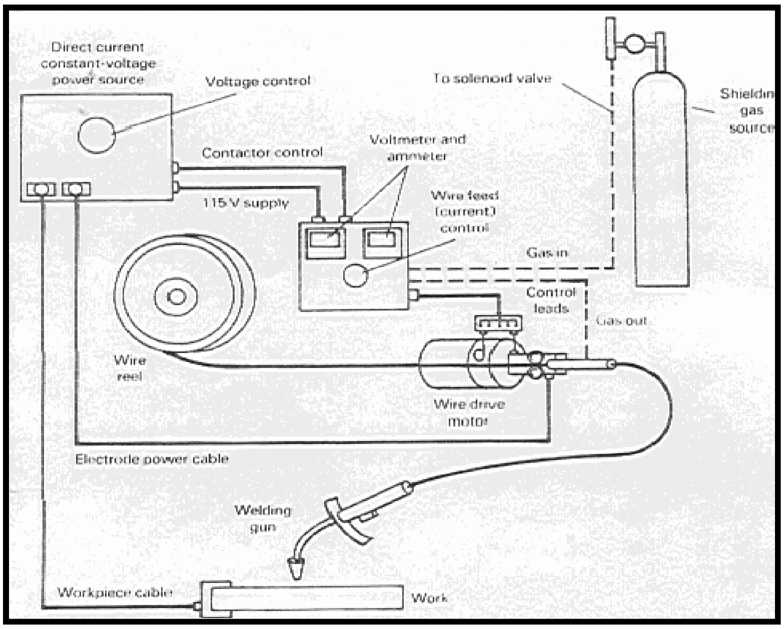


**Figure-1:** A schematic line diagram of the GMAW process.

Shielding in GMAW process is obtained from an externally supplied gas or gas mixture. The process (GMAW) is also sometimes referred to by its subtypes, metal inert gas (MIG) welding or metal active gas (MAG) welding depending on the nature of the shielding gas fed through the welding gun. For CO2 shielding it is called MAG and for Argon/ Helium shielding it is generally referred to MIG.

## 2.0 ABOUT THE PROCESS:

A constant voltage, direct current power source (shown in figure-2) is most commonly accepted for GMAW process though alternating current power sources are also used.

The welding procedures for GMAW welding are similar to those for other arc welding processes. Adequate fixturing and clamping of the work are required with adequate accessibility for the welding gun. Good connection of the ground lead to the work-piece or fixture is required. The location of the connection is important, particularly when welding ferromagnetic materials such as steel.


**Figure-2:** Photograph of welding machine and also the wire feeder.

The best direction of welding is away from the work lead connection.

The position of the electrode with respect to the weld joint is important in order to obtain the desired joint penetration, fusion, and weld bead geometry. When complete joint penetration is required, some method of weld backing helps to control it. A backing strip, porcelain strip or copper backing bar can be used. Backing strips and porcelain strips usually are disposable type whereas copper backing bars are removable & can be re-used.

The photograph of the welding gun and details of the functional variables of GMAW process are detailed in figure-3.

All gas and water connections should be tight; there should be no leaks. Aspiration of water or air into the shielding gas will result in erratic arc operation and contamination of the weld. Porosity may also occur.

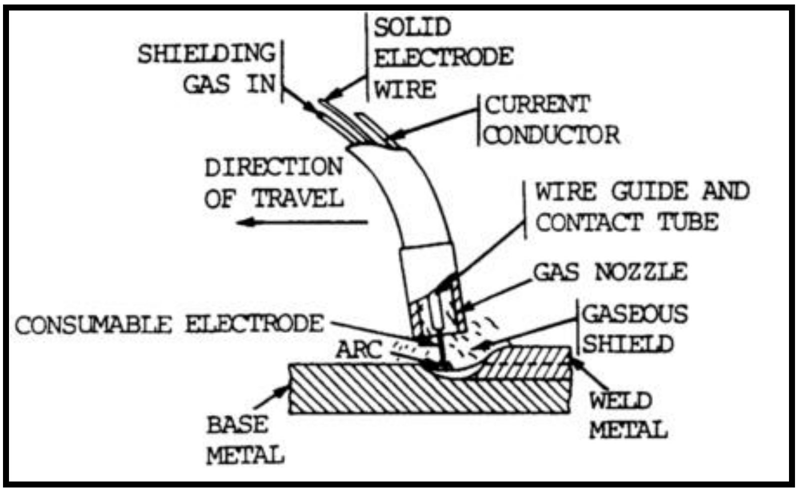


**Figure-3:** Schematic sketch of welding torch & description of various parts.

Joint designs that require long nozzle-to-work distances will need higher gas flow rates than those used with normal nozzle-to-work distances. When welding is done in confined areas or in the root of thick weld joints, small size nozzles are used.

The contact tube will wear with usage, and must be replaced periodically if good electrical contact with electrode is to be maintained and heating of the gun is to be minimized.

Electrode extension is set by the distance between the tip of the contact tube and the gas nozzle opening. The extension used is related to the type of MIG welding, short circuiting or spray type transfer.  It is important to keep the electrode extension (nozzle-to-work distance) as uniform as possible during welding. Therefore, depending on the application, the contact tube may be inside, or extending beyond the gas nozzle.

The electrode feed rate and welding voltage are set to the recommended values for the electrode size and material. A trial bead weld should be made to establish proper voltage (arc length) and feed rate values.

Other variables, such as slope control, inductance, or both, should be adjusted to give good arc starting and smooth arc operation with minimum spatter. The optimum settings depend on the equipment design and controls, electrode material and size, shielding gas, weld joint design, base metal composition and thickness, welding position, and welding speed.

The wire feed & gas flow starts immediately as the power switch is on. But while stopping the operation, the wire feed rate should stop first (few seconds earlier) and then the gas flow rate. This sequence of functional activities during the welding operation is schematically shown in figure-4.

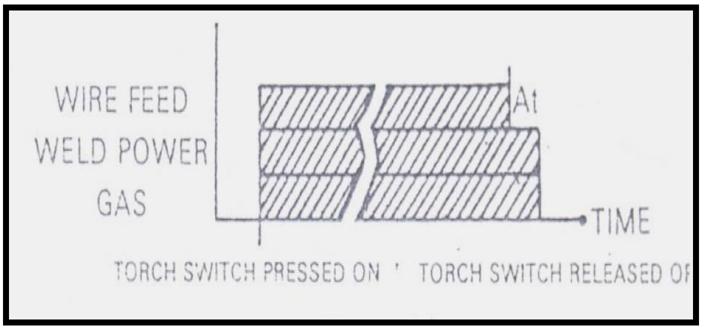


**Figure-4:** Graphical representation of functional operations in GMAW.

## 3.0 MECHANISM OF METAL TRANSFER:

Among the different metal transfer modes in GMAW, the most commonly observed mechanisms referred by the International Institute of Welding (IIW) are: Short Circuiting, Globular, Spray and Streaming. The significant parameters which influence the type of transfer are:

- Nature and magnitude of welding current
- Diameter of electrode wire
- Composition of electrode wire
- Extension of electrode beyond the tip
- Type of shielding gas and
- Power supply output

The typical current ranges for metal transfers are shown in Table-1.

**Table 1:** Typical current ranges for GMAW of C-steel for various metal transfers.

| | Welding Current, DCEP | |
|---|---|---|
| Wire Diameter | Spray type arc | Short-circuiting arc |
| (mm) | (30-45V) | (16-22V) |
| 0.80 | 150-250 | 60-160 |
| 1.20 | 200-350 | 100-175 |
| 1.60 | 350-500 | 120-180 |

**3.1 Short circuiting transfer –** It uses the lowest range of welding currents and electrode diameters associated with MIG welding. This type of transfer produces a small, fast-freezing weld pool that is generally suited for the joining of thin sections, out-of-position welding, and filling of large root openings. When weld heat input is extremely low, plate distortion is small. Metal is transferred from the electrode to the work only during a period when the electrode is in contact with the weld pool. There is no metal transfer across the arc gap.

The electrode contacts the molten weld pool at a steady rate in a range of 20 to over 200 times each second. As the wire touches the weld metal, the current increases. It would continue to increase if an arc did not form. The rate of current increase must be high enough to maintain a molten electrode tip until filler metal is transferred. It should not occur so fast that it causes spatter by disintegration of the transferring drop of filler metal. The rate of current increase is controlled by adjustment of the inductance in the power source. The value of inductance required depends on both the electrical resistance of the welding circuit and the temperature range of electrode melting. The open circuit voltage of the power source must be low enough so that an arc cannot continue under the existing welding conditions. A portion of the energy for arc maintenance is provided by the inductive storage of energy during the period of short circuiting.

As metal transfer only occurs during short circuiting, shielding gas has very little effect on this type of transfer. Spatter can occur. It is usually caused either by gas evolution or electromagnetic forces on the molten tip of the electrode.

**3.2 Globular transfer** – This type of transfer takes place wth a positive electrode (dcrp) and when the current density is relatively low, regardless of the type of shielding gas. However, carbon dioxide ($CO_2$) shielding yields this type of transfer at all usable welding currents. Globular transfer is characterized by a drop size of greater diameter than that of the electrode.

Globular, axially directed transfer can be achieved in a substantially inert gas shield without spatter. The arc length must be long enough to assure detachment of the drop before it contacts the molten metal. However, the resulting weld is likely to be unacceptable because of lack of fusion, insufficient penetration, and excessive reinforcement.

Carbon dioxide shielding always yields non-axially directed globular transfer. This is due to electromagnetic repulsive force acting upon the bottom of the molten drops. Flow of electric current through the electrode generates several forces that act on the molten tip. The most important of these are pinch force and anode reaction force. The magnitude of the pinch force is a direct function of welding current and wire diameter, and is usually responsible for drop detachment. With CO2 shielding, the wire electrode is melted by the arc heat conducted through the molten drop. The electrode tip is not enveloped by the arc plasma. The molten drop grows until it detaches by short circuiting or gravity.

**3.3 Spray transfer** – The process has a typical fine arc column and pointed wire tip associated with it. Molten filler metal transfers across the arc as fine droplets. The droplet diameter is equal to or less than the electrode diameter. The metal spray is axially directed. The reduction in droplet size is also accompanied by an increase in the rate of droplet detachment, as illustrated in figure 10-47. Metal transfer rate may range from less than 100 to several hundred droplets per second as the electrode feed rate increases from approximately 40 to 340 mm/s).

In a gas shield of at least 80 percent argon or helium, filler metal transfer changes from globular to spray type as welding current increases for a given size electrode. For all metals, the change takes place at a current value called the globular-to-spray transition current.

**3.4 Streaming transfer** – The increase in current and with wire speed, the spray transfer changes to streaming transfer. The arc characteristic cone shape and can involve as high as 1000 drops/second.

## 4.0 CLASSIFICATION SYSTEM AS PER AWS A 5.18 STANDARD:

**E R X S - X Y N H Z**

(a) (b) (c) (d) (e) (f) (g)

(a) Indicates use as either as an electrode or rod (ER) or use only as an electrode (E).

(b) Indicates in 1.0 ksi increments, the minimum tensile strength of the weld metal produced by the electrode.

(c) Indicates whether the filler metal is solid (S) or composite (C).

(d) The chemical composition of the solid electrode (Table 2). The use of the suffix ‘GS’ designates filler metals intended for single-pass applications only.

(e) Indicates the type of shielding gas used. Carbon dioxide shielding is indicated by ‘C’ and 75-80% Ar/balance $CO_2$ is indicated by ‘M’.

(f) The letter ‘N’ indicates that the weld metal is intended for the core belt region of nuclear reactor vessels. The suffix limits P (0.012% max.), V (0.05% max.) and Cu (0.08% max.).

(g) Indicates the optional requirements of diffusible hydrogen in the deposited weld metal. H4, H8, H16 represents average maximum allowable diffusible hydrogen to be of 4, 8 and 16 ml/100 gm respectively.

## 5.0 VARIOUS GRADES OF GMAW WIRES:

The common grades of GMAW wires along-with their composition are mentioned in table-2.

Table 2: Chemical composition (wt.%) requirements from solid electrodes

| AWS | UNS No | C | Mn | Si | P | S | Ti | Zr | Al |
|---|---|---|---|---|---|---|---|---|---|
| ER70S-2 | K10726 | 0.07 | 0.9-1.4 | 0.4-0.7 | 0.025 | 0.035 | 0.05-0.15 | 0.02-0.12 | 0.05-0.15 |
| ER70S-3 | K11022 | 0.06-0.15 | 0.9-1.4 | 0.45-0.75 | 0.025 | 0.035 | - | - | - |
| ER70S-4 | K11132 | 0.07-0.15 | 1.0-1.5 | 0.65-0.85 | 0.025 | 0.035 | - | - | - |
| ER70S-5 | K11357 | 0.07-0.19 | 0.9-1.4 | 0.3-0.6 | 0.025 | 0.035 | - | - | 0.5-0.9 |
| ER70S-6 | K11140 | 0.06-0.15 | 1.4-1.85 | 0.8-1.15 | 0.025 | 0.035 | - | - | - |
| ER70S-7 | K11125 | 0.07-0.15 | 1.5-2.0 | 0.5-0.8 | 0.025 | 0.035 | - | - | - |
| ER70S-G | - | ← Chemical composition is not specified → | | | | | | | |

(a) Dashed line shows, value not mentioned. (b) Single values are maximum percentages.

## 6.0 SELECTION OF PROCESS PARAMETERS:

A strict control over the welding parameters is mandatory for achieving quality and high-productive joint in both GMAW and FCAW processes. The characteristic features of each variable are summarized below.

**6.1 Welding Current** – The welding current is proportional to electrode feed rate provided the composition, diameter and extension of electrode remains unaltered.

| | |
|---|---|
| 1) | Deposition rate increases with increase in welding current. |
| 2) | Increase in current increases weld bead penetration. |
| 3) | A poor appearance & convexity of weld bead appears with excessive current. |
| 4) | Insufficient current produces large droplet & causes excessive spatter. |

**6.2 Arc Voltage** – The arc voltage that is shown in the meter of the power supply is the sum of total voltage-drop in the welding circuit. This includes; the drop through the welding cable, the electrode extension, the arc, the work piece and the ground cable. Therefore, all other circuit elements are to be constant to obtain proportionate meter reading and arc voltage.

| | |
|---|---|
| 1) | Too high an arc voltage will result in excessive spatter and wide, irregularly shaped weld beads. A long arc gap during welding promotes more pick up of nitrogen from atmosphere. For mild steel it will result to form porosities and in stainless steels a lowering of ferrite content which in turn may cause for solidification cracking. |
| 2) | Too low an arc voltage (too short an arc) will result in narrow and convex beads with excessive spatter and poor penetration. |

**6.3 Electrode Extension** – The length of the wire extended beyond the tip of the nozzle to the arc pool is referred as the electrode extension. It affects the shielding conditions, arc energy, electrode deposition rate and weld penetration. Generally, an extension of 19 to 38 mm for gas shielded electrodes and approximately 19 to 95 mm for self-shielded electrodes can be applicable depending on the application.

| | |
|---|---|
| 1) | Longer arc extension results to form an unstable arc with excessive spatter. In gas shielded metal arc welding it results poor gas coverage of the weld pool resulting porosities and related defects. |
| 2) | Too short an arc length is also undesirable due to excessive spatter. |

**6.4 Travel Speed** – Heat input in the weld is inversely proportional to the arc travel speed. So, both too high and too low a travel speed is equally detrimental to the weld metal quality. It also results to form a poor bead appearance with a possibility of entrapped slag for higher arc travel speeds.

**6.5 Shielding Gas Flow** – The gas flow rate is an important factor to obtain a good quality weld joint. A poor shielding will result for a low gas flow rate, on the other hand too high a flow rate will create turbulence in the molten weld puddle causing porosities, slag entrapment and poor weld bead appearance. The correct gas flow rate should be selected on type and diameter of the gun nozzle, nozzle to work distance and rate of air flow in the vicinity of the welding operation.

**6.6 Electrode Angle** – The angle of the electrode determines the direction of arc force applied to the weld pool. Proper drag angle (between the weld axis and vertical plane) is maintained to achieve the desired weld penetration for thin or thick sections. Usually a lower drag angle (2° to 15°) is maintained for gas-shielded arc welding. The effectiveness of the shielding gas is lost with higher welding angle and generally it does not exceed 25°. For fillet welds in horizontal position, the liquid metal in the weld pool tends to flow in the welding direction as well as right angle to it. A work angle (between the axis and the vertical member) of 45° to 50° is thus used to counteract the flow in the latter direction.

## 7.0 WELDING TECHNIQUE:

Gun position or Welding technique usually refers the way in which the gun is hold in a position with respect to the work piece. Depending on the progress of travel the welding technique may either be a push technique, a drag technique or a perpendicular technique (Figure-5).

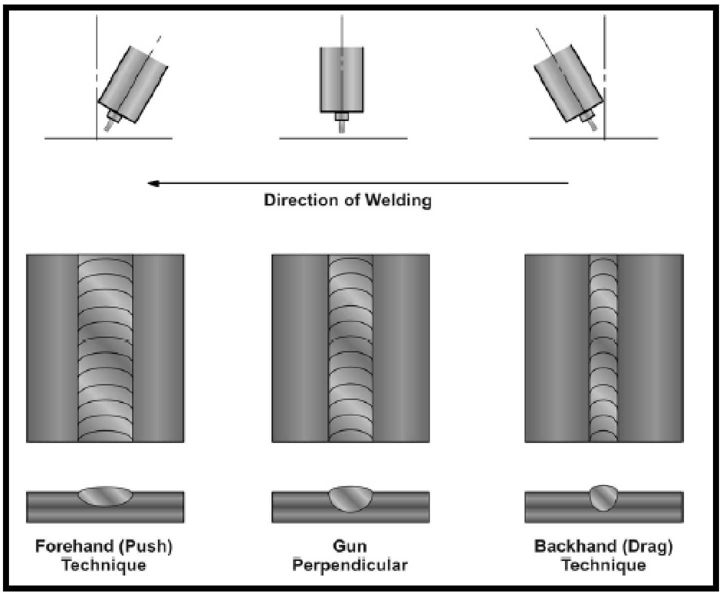


**Figure-5:** Schematic representations of various welding techniques.

Forehand technique is also referred as Push or Leading technique. The gun is pointed away from the weld puddle and is “pushed” away from the weld. Low penetration and faster travel speed facilitates this process as an advantage for thin sheet welding and for hard surfacing. Generally push techniques offer a better view of the weld joint and the direction of wire into the groove.

In perpendicular technique the wire is fed straight into the weld instead of any angle.

A Backhand technique also sometimes is referred as, Drag, Pull or trailing technique. The bead in this technique becomes narrower and results more build up. Considering all the welding variables remaining same, the penetration obtained in this technique is more as the arc is directed towards a preheated base metal.